

**FINAL**  
**NICOR Operated Gas Storage Fields**  
**Estimate of Top/Base**  
**And**  
**Recoverable/Non-Recoverable Gas Volumes**

Prepared for  
**Nicor** Gas, Inc.

**October 25, 2004**

Prepared by



*Fairchild and Wells, Inc.*  
PETROLEUM AND ENVIRONMENTAL CONSULTANTS

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October 25, 2004

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**Re: Estimate of Top/Base and Recoverable/Non-Recoverable Gas Volumes  
NICOR Operated Gas Storage Fields**

Dear Mr. McCaffrey:

## SUMMARY

This letter report summarizes my estimates of the **top/base** and recoverable/non-recoverable gas volumes for the eight Nicor Gas, Inc. (NICOR) operated storage fields. The techniques I applied in making these gas volume estimates are generally accepted reservoir engineering methods for evaluating or for making reserve estimates of a water-drive gas reservoir. The aquifer storage system is analogous to the water drive gas reservoir. The different calculations used and how they apply to this study are discussed below.

My gas volume estimates for each field (reservoir) are presented below along with the maximum gas inventory as achieved by NICOR.

**Table 1**

STORED GAS VOLUMES Nicor Gas, Inc.							
Field	Maximum Inventory mmscf	Date Achieved mmscf	Top Gas mmscf	Base Gas mmsd	Recoverable Base Gas mmsd	1995 Study Non-Recoverable Base Gas % Maximum Inventory	Non-Recoverable Base Gas mmscf
Ancona	172,826	10/26/03	60,900	111,926	36,418	43.69	75,508
Hudson	46,854	11/29/01	10,250	36,604	8,328	60.35	28,276
Lake Bloomington	49,538	11/19/01	8,400	41,138	4,396	74.17	36,742
Lexington	52,185	11/12/01	8,250	43,935	5,130	74.36	38,805
Pecatonica	3,286	12/5/98	1,720	1,566	421	34.85	1,145
Pontiac - Galesville	18,737	12/13/01	8,500	10,237	3,377	36.61	6,860
Pontiac - Mt. Simon	42,864	12/16/01	3,720	39,144	6,439	76.30	32,705
Troy Grove	79,976	11/26/01	48,000	31,976	9,199	28.48	22,777
<b>TOTAL</b>	466,266		149,740	316,526	73,708		242,818

The reservoir engineering methods applied in the study are discussed in the sections which follow. The data used in the study included historical **pressure/production** data for each storage project, NICOR **geological/engineering** review reports and the knowledge gained from working with NICOR on these storage projects over the last twenty years.

In 1995, we performed a similar study of the NICOR storage fields (Reference letter to Mr. Gary Jones dated February 24, 1995). Since this study, NICOR increased the maximum inventory (in total) by approximately 13,800 **mmscf** or about 3.1 percent. With the exception of Pecatonica, maximum inventory was increased in all other fields.

For the purpose of this study, the **top gas**<sup>1</sup> is the volume of gas in the reservoir above the design level of base gas. It may or may not be completely withdrawn during any particular storage season. The **base gas**<sup>1</sup> is the volume of gas required in a storage reservoir to provide the volume and pressure to cycle the normal top gas volume. **Recoverable gas**<sup>2</sup> is the gas considered recoverable assuming the storage reservoir is placed on production and depleted to abandonment. The difference between the total volume (top plus base) in storage and total recoverable gas in storage is the **non-recoverable gas**. The non-recoverable gas is essential to the storage operation.

## ENGINEERING ANALYSIS

### **Top Gas/ Base Gas**

Two different methods of extrapolating actual field performance data were generally used to estimate the **top/base** gas for each storage project; (1) gas withdrawal rate versus cumulative gas produced (Gp), and (2) calculated reservoir performance **coefficients** (C-factors) versus percent of inventory out. The calculated C-factors are based on reservoir pressure, flowing wellhead pressure and withdrawal rate. In both cases, the cumulative gas produced and the percent of inventory out were based on actual annual withdrawal cycle gas volumes. This analysis considered the 2000–01, 2001–02, 2002-03 and 2003–04 withdrawal cycles.

### ***Rate vs. Gp (Storage Gas Withdrawn)***

The projection of gas rate versus cumulative gas produced is an accepted method for determining the maximum produced volume under a constant set of producing constraints. This is one method used in this study to determine the top gas volume. There is, however, a judgment factor required in making this extrapolation. For example, is the rate decline a direct result of declining reservoir pressure, or are other factors involved as water production or expected future water production? Both of these are the case for the NICOR aquifer storage projects.

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<sup>1</sup> *Survey of Underground Gas Storage Facilities in the United States and Canada, American Gas Association, 1993.*

<sup>2</sup> *The Underground Storage of Gas in the United States and Canada, American Gas Association, 1978.*

Figures 1 through 8 show the Withdrawal Rate versus Gp for the 2000-01 through 2003-04 withdrawals for each storage project. As will be noted, the extrapolations for the south fields, Hudson, Lake Bloomington, Lexington and Pontiac Mt. Simon are straight forward since there is a dramatic decline in rate generally caused by water production. For **Ancona**, Pontiac Galesville and Troy Grove, where high deliverabilities are achievable throughout the withdrawal season, it is more difficult to make this extrapolation. The rate extrapolation for Pecatonica also required a degree of interpretation. My extrapolations for each project are shown on Figures 1 through 8.

In some cases, different withdrawal cycles will extrapolate to a different Gp since the decline in the historical rate is a function of the withdrawal schedule early in the cycle and the injection from the previous cycle. These differences are obvious when reviewing the withdrawal rate versus Gp figures.

#### ***Performance Coefficients vs. Percent of Inventory Out***

The second method was to extrapolate the Performance Coefficients versus Percent of Inventory Out plots provided on select fields by NICOR. These charts, Figures 9 through 13, are based on actual field performance data and reflect the flowing pressure constraints, the number of wells on line on any given day, reservoir pressure and water production. My extrapolations are shown on each figure. These extrapolations to a top gas volume are consistent with top gas volumes as determined **from** the rate versus Gp extrapolations.

#### ***Water Production vs. Cumulative ~~Gas~~ Produced***

Figures 14 through 16 show the produced water for the 2000 – 2004 withdrawal cycles as barrels water produced per day per mmscf of gas produced for Hudson, Lake Bloomington and Lexington. For all three fields, the produced water increases as the cumulative gas produced in a cycle increases. This is consistent with the decrease in the C-factors.

The estimated top gas for **Ancona**, Hudson, Lake Bloomington, Lexington, Pecatonica, Pontiac Galesville, Pontiac Mt. Simon and Troy Grove was determined to be 60900, 10250, 8400, 8250, 1720, 8500, 3720 and 48000 mmscf, respectively, based on the empirical relationships of Rate vs. Gp **and/or** C-Factor vs. Percent Inventory Out methods.

#### **Non-Recoverable Base ~~Gas~~**

The non-recoverable (total base gas minus recoverable base gas) base gas was estimated in the 1995 study by use of the P/z versus Gp function and gas-water material balance calculations coupled with analytical water **influx/efflux** calculations. It was assumed that the withdrawal pressure constraints as used in storage operations would no longer be the limiting factors since the reservoir is being produced to abandonment.

### *P/z versus G<sub>p</sub>*

One of the most common methods for predicting gas reserves is to graphically solve the gas material balance equation. This technique involves plotting the **P/z** versus cumulative gas produced, **G<sub>p</sub>**. For a volumetric reservoir the **P/z** is linear and the extrapolation to zero **P/z** represents the original gas-in-place and gas reserves are generally determined by making an independent determination of the reservoir abandonment pressure. In the conventional case, the gas-in-place is **an** unknown, therefore, this method is proven to be valuable to support volumetric calculations based on structure, net sand, gas saturation and porosity maps. In aquifer storage, however, we believe we know the gas-in-place at any point in time since the net gas in the reservoir is a metered volume. Therefore, the deviation **from** the volumetric straight line is the influence of the aquifer system or water **efflux/influx** as gas is either injected or withdrawn. The significance of the water-drive is directly related to the deviation **from** the volumetric line. The Reservoir Pressure vs. Cumulative Gas Produced relationships for each NICOR field are attached as Figures 17 through 24. It is also common to use reservoir pressure in place of **P/z** in developing an empirical relationship.

These figures also compare the reservoir pressure vs. cumulative gas produced **from** the 1995 study. The comparison is good for most fields. Where there are differences it not believed this difference will change the estimated non-recoverable gas when expressed as a percent of the maximum inventory.

### *Material Balance and Water Influx*

In the 1995 study, material balance studies of each field employing the following equation were used to **quantify** water influx.

$$G_{pn}B_{gn} = G(B_{gn} - B_{gi}) + B_w(W_{en} - W_{pn})$$

where:	$B_g$	=	$(TP_{sc}Z) / (5.61 5T_{sc}P)$ , <b>rb/scf</b>
	$B_w$	=	water formation volume factor, <b>rb/stb</b>
	$G$	=	original gas-in-place, <b>scf</b>
	$W_e$	=	cumulative water influx, <b>stb</b>
	$W_p$	=	cumulative water produced, <b>stb</b>
	$G_p$	=	cumulative gas produced, <b>scf</b>

To calculate water influx, **W<sub>e</sub>**, we have used the method of **Carter-Tracy**<sup>3</sup>. This technique is **an** accepted method and is used in most reservoir simulators.

We have demonstrated that these procedures can be successfully applied to the analysis of gas storage in underground aquifers through numerous studies. In the normal reservoir analysis, the

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<sup>3</sup> *An Improved Method for Calculating Water Influx*, SPE AIME Transactions Vol. 219, pp 415-417, T.N 2072, 1960.

gas-water material balance equation represents one equation with two unknowns, gas-in-place and water influx. Our **task**, for the aquifer storage studies reduces, however, to the determination of water **influx/efflux** ( $W_e$ ) since the gas-in-place at any point in time is known. Therefore, the  $W_e$  is the volume required to support the historical measured pressure profile for a given storage field.

The material balance and water influx technique was used for each reservoir, except for Pecatonica, with good success. We have utilized a non-linear regression procedure to determine the "best-fit" aquifer parameters to achieve a good match of the calculated and observed reservoir pressures since the start of gas storage. The material balance models were then used to project reservoir pressure under a **blowdown** operation. From these material balance calculations, we have a reasonable estimate of the volume and rate of water movement in the various NICOR fields as a function of time and storage activity.

It was determined that a reasonable estimate of the non-recoverable gas would be where the calculated Plz versus Gp "flattened" or where the water influx was maintaining pressure for the specified gas withdrawal rates. Since pressure is no longer decreasing, there would be no additional gas recovery from gas expansion. Based on our experience, this is also the time in the life of a reservoir where the major portion of reserves have been produced.

From this technique of using Plz versus Gp and the material balance calculations, it was determined that the estimated non-recoverable gas volumes for Ancona, Hudson, Lake **Bloomington**, Lexington, Pontiac Galesville, Pontiac Mt. Simon and Troy Grove are represented by 43.69, 60.35, 74.17, **74.36**, 34.85, 36.61, 76.30 and 78.48 percent, respectively, of the maximum inventory. The non-recoverable gas volume for Pecatonica was based on a recovery factor of 65%. This recovery factor is consistent with the recovery factors for the other storage fields based on the historical performance of the various reservoirs.

As noted above, the current pressure volume performance of each reservoir has not changed significantly. Since the early 1990's there have been only minor changes in the operations of the fields. These changes, including the small percentage change in maximum inventory, would not materially change the estimate of non-recoverable base gas as determined in the 1995 study.

### **Recoverable Base Gas**

The recoverable base gas was determined as the maximum inventory minus the top gas and non-recoverable base gas. These estimated volumes are shown in the summary Table 1.

The gas volumes included in this report are estimates only and should not be construed as being exact quantities. Future operations could have an impact on these estimated volumes. In the preparation of this report and the conclusion derived **from** the studies, certain assumptions were made which may occur in the future regarding operations. Although we believe these assumptions are reasonable for the purpose of this report, changes occurring or becoming known after the date of the report could **affect** the material presented herein.



Should you require additional information, or have questions regarding the methodology as used in the study, please give me a call.

Sincerely,

*James W. Fairchild*

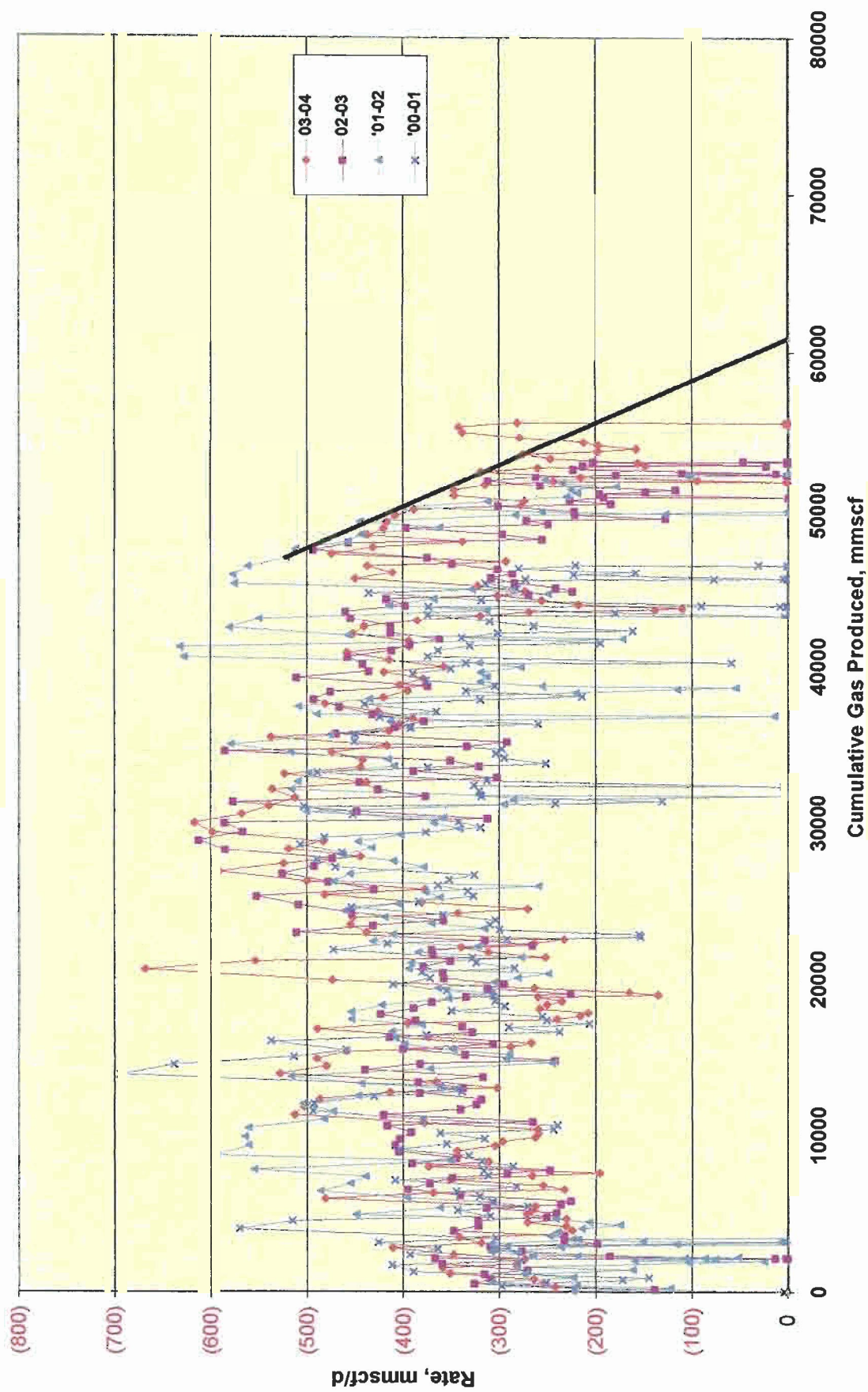
James W. Fairchild  
President

cc: Neil Maloney w/attachment ✓

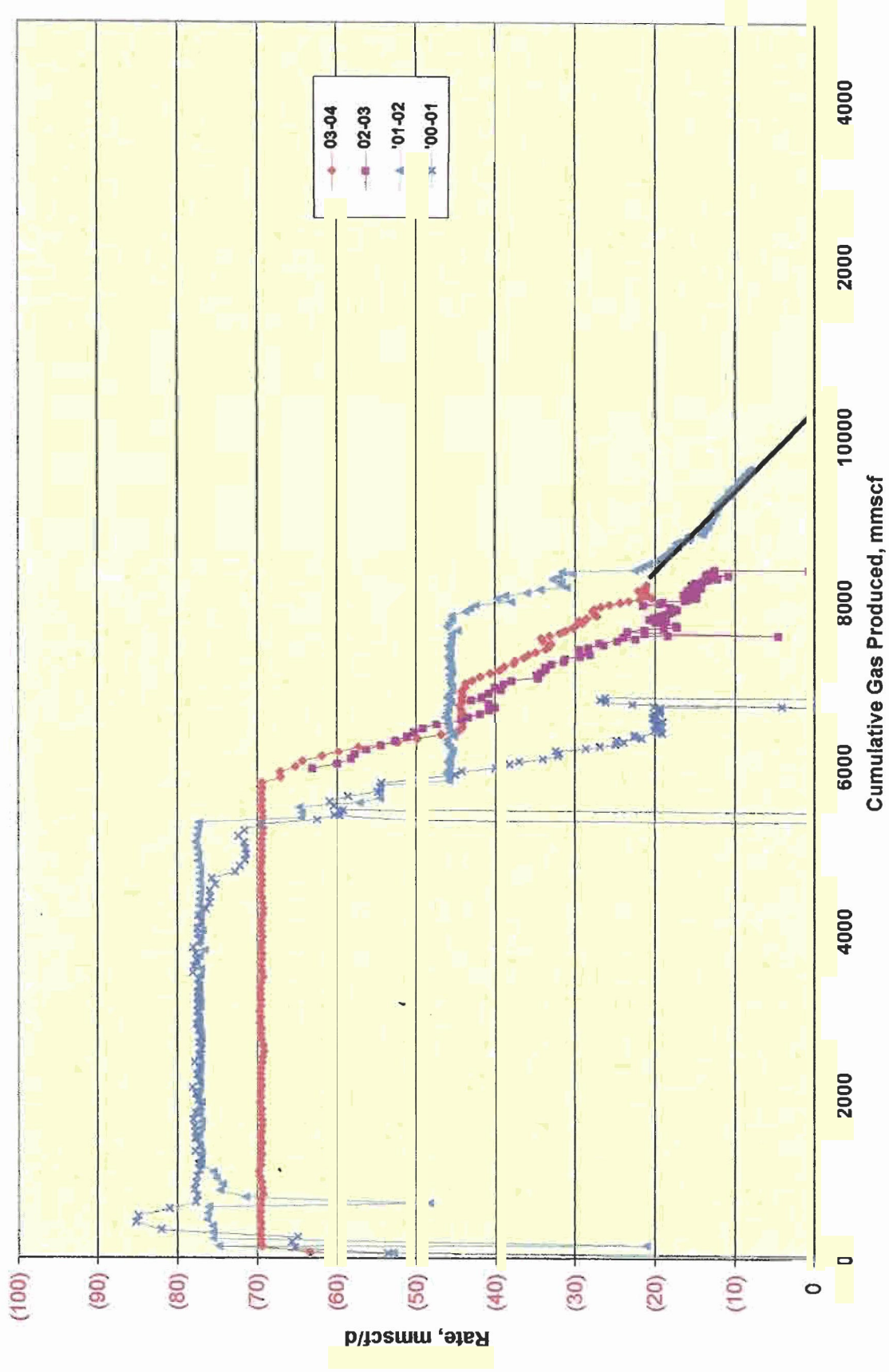
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Attachments (Figures 1-24)

## FIGURES

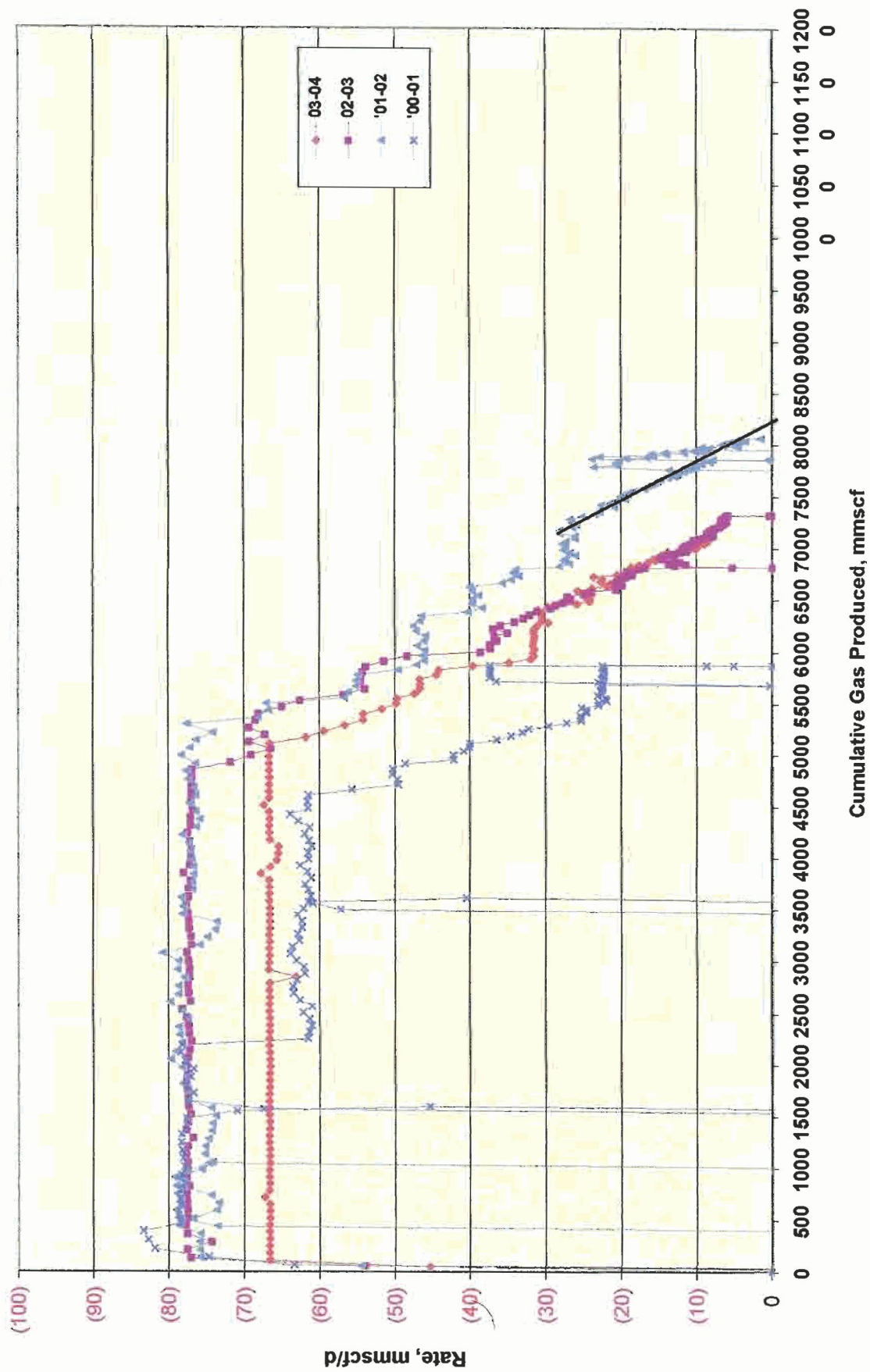
**FIGURE 1**  
**NICOR - Ancona**



**FIGURE 2**  
**NICOR - Hudson**



**FIGURE 3**  
**NICOR - Lake Bloomington**





**FIGURE 4**  
**NICOR - Lexington**

